NLC - The Next Linear Collider Project

LHC Collimator R&D Plan

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SLAC

LARP
Fermilab
27 February 2004

Rudimentary R&D Plan Exists

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Rotating "Consumable" Collimators for LHC Phase II Operation

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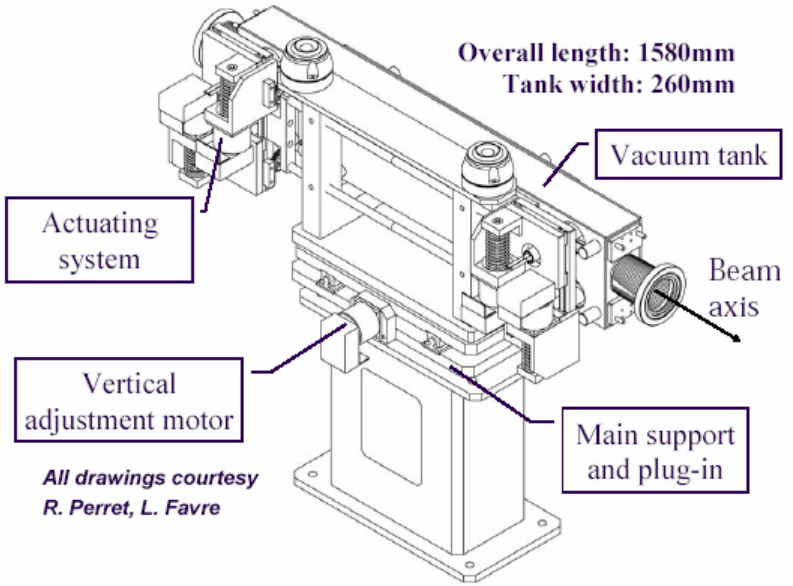
Abstract

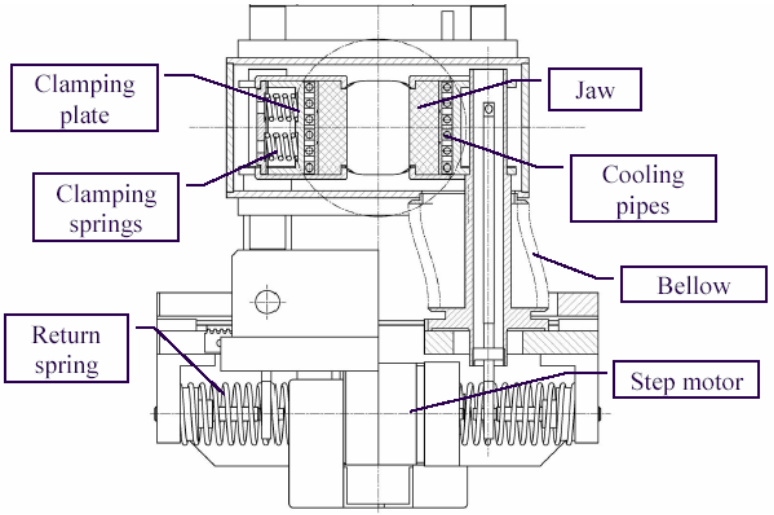
SLAC has developed a prototype collimator for the NLC based on two 30-cm diameter, 10-cm wide wheels referenced to a common base plate with bearing to set the collimator gap. The device operates in vacuum and is not externally cooled. A ratcheting mechanism moves the wheels ~1mm azimuthally while maintaining the gap position and gap width. If the collimator surface is damaged by a high power density errant beam it can be rotated to a fresh position approximately 1000x.

The LHC beam abort system is expected to accidentally fire at a very low but non-zero rate; at design luminosity the beam will damage the collimators. The LHC collimators are 50cm thick and must have 1kW of average cooling. We propose to adapt the NLC collimator design to the LHC situation, fabricate prototypes, perform vacuum and beam tests, and deliver a drawing package that CERN can use to industrially fabricate the required number (between 5-10) of collimators.

The collimator design, prototyping and testing would is planned for 2004-2007; collimator production would occur in 2008, and installation and commissioning in 2009. The non-production total estimated cost is $2.3M$.

LHC Phase I Carbon/Carbon Collimators





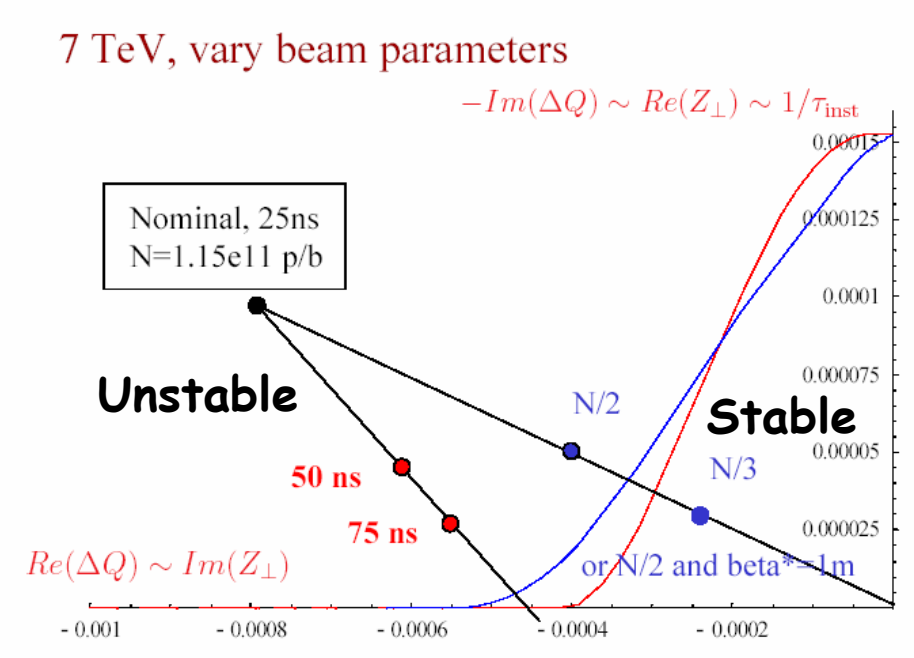
Length: 1200 mm
Stroke: 35 mm (30+5mm)
Gap: 0.5 mm
Flatness tolerance: 25 μm
Angulary tolerance: 15 μrad
Motor step size: 10μm
Roughness: 1 μm
Coating: 1 μm

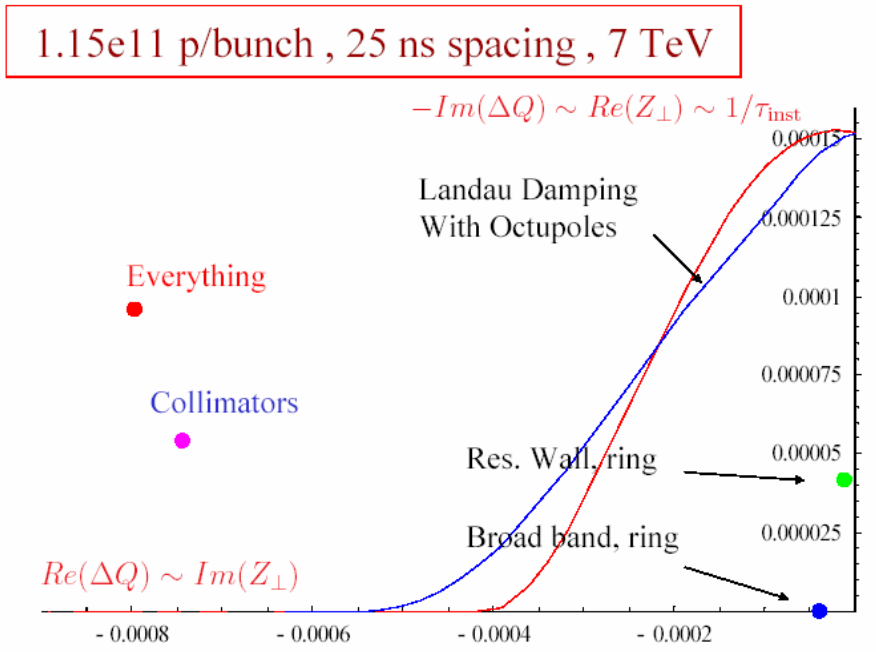
Loss conditions:

Steady State: 8E10p/s (90kW) ⇒6.4kW
Peak: 4E11p/s (450kW) over 10 sec⇒32kW

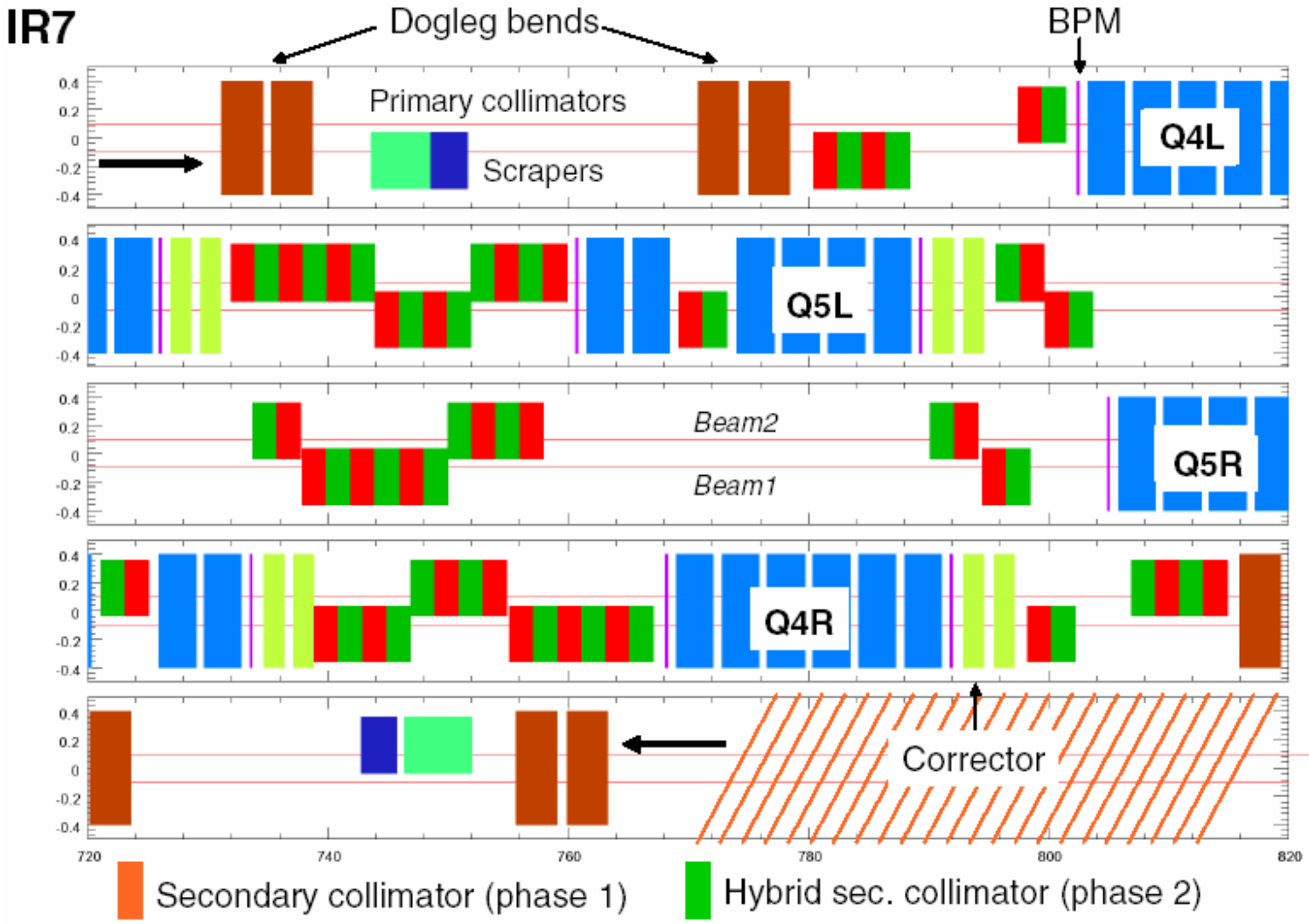
Jaws fully adjustable (same mechanism used for H, V & 45° collimators)
Jaw max temperature: 50°C (limited by outgassing outgassing rates)
Vertical adjustment: ±10mm

Impedence Limits Luminosity
Collimators Dominate Impedence



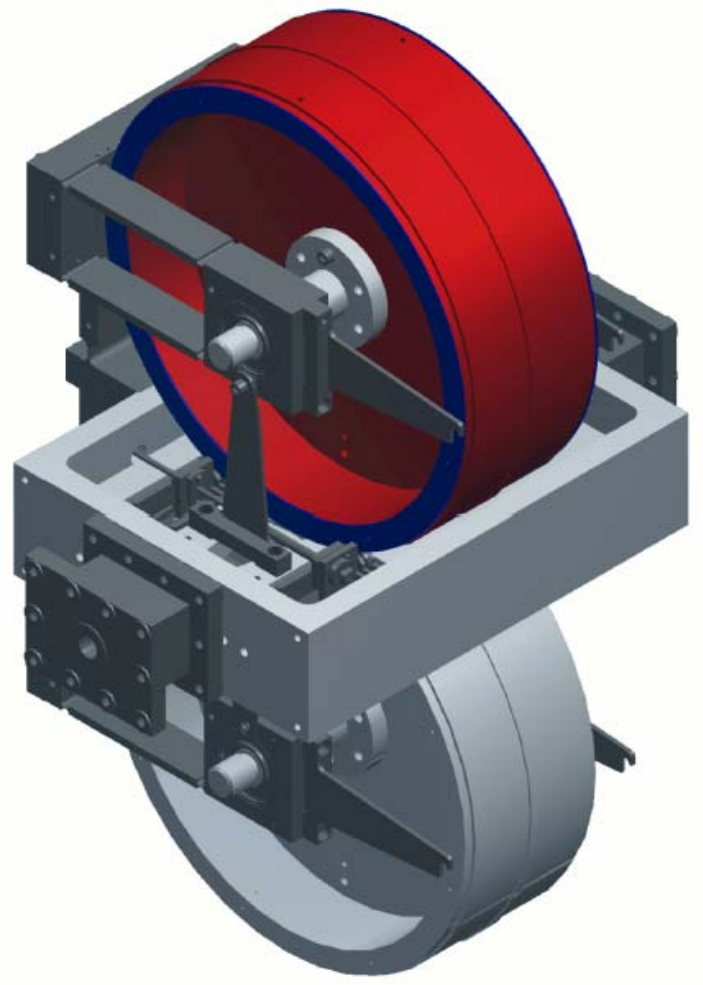


32 2m spaces left downbeam of each Phase 1 collimator- 5-10 are high risk



Quad movements up to 1m, collimator movements up to 30 m! 40% of space for collimators!

NLC Rotating Collimator



NLC Consumable Spoiler Requirements

Max.# Damaging Hits	1000
Length @ Min. Gap	0.6 rl
Radius of curvature	.5 m
Aperture	200-2000 μm
Edge Placement Accuracy	10-20 μm
Edge Stability under rotation	5 μm
Beam Pipe ID	10 mm
% Beam Intercepted per side	.05%
Beam Halo Heating	~0.2 W
Image Current Heating	~0.5 W
Radiation Environment	10^5-10^6 rad/hour
Vacuum (tbd)	$<10^{-7}$ torr

~30cm diameter

7mm Cu + Be wings

Radiative Cooling

LHC Phase II Collimator Specs
NLC-like but Larger & w/Cooling

Length	1-2m
Material & Wakes	Presumably metal, needs study
Gap, Alignment, Stroke	as Phase I, similar to NLC specs
Vacuum	UHV, in situ baked to 250-300°C
Radiation Hardness	Inorganics Only
# Accidents Allowed	"5", needs discussion
Power	Needs study
Accident	8x1.15E11 protons
Peak Loss	4E11p/s over 10s x absorption efficiency
Steady Loss	8E10p/s x absorption efficiency
Cooling	Several kW within 1cm of surface
Transverse space	Fit within 192-224mm space between beamlines
Types	Ideally, H,V & 45°

Recent History

- Original R&D Plan reviewed, detailed and given to Jim Strait and Steve Peggs on Jan. 15, 2004
- Chamonix XIII meeting and subsequent visit with Assmann at CERN better defines state of project
- Jim gets DOE budget guidance & LARP executive committee formally agrees to include collimator task in its brief
- This information sent to Tor Raubenheimer and TWM on 22 February and passed to SLAC director Jonathan Dorfan on 23 February
- In short meeting on 25 February, Dorfan agrees to participate in project subject to stipulations to be made in a forthcoming M.O.U.

MOU Guidelines from Director

- **Collimator project is an aggressive R&D project with a hard deadline and no guarantees**
  - Need to carefully define the collimator project scope
  - SLAC's budget has little room to provide additional support
- **Suggestion**
  - SLAC will participate with CERN in defining specifications of Phase II collimator system
  - CERN will sign-off on the specs
  - SLAC will design and build prototype to these specs
    - Commitment ends with delivery of prototype and drawing package
  - SLAC will "participate in the collimator commissioning" but cannot be responsible for "commissioning the LHC collimator system"

Proposal on the Table

- **Main Deliverable**
  - Develop a prototype rotating collimator with cooling and appropriate length/materials for the LHC Phase-II
- **Support for Phase I collimators, if desired and appropriate**
  - Measure short and long-range wakefields from LHC Phase-I collimators using the COLWAKE facility
  - Perform material damage studies on LHC Phase-I collimator materials in SLAC FFTB coupon test facility

September 2003 Plan

2004	2005	2006	2007	2008
Coupon Tests COLWAKE	Coupon Tests COLWAKE	X	X	X
Finish PO Specifcations ·Lattice ·Materials	Design P1 Build P1 Test P1 Design P2 Build P2	Test P2 Design P3 Build P3	Build P3 Test P3 Design P4 Build P4	Construct 5-10 Collimators
$75k M&S + Shop	$25K+125k+ 75k=$225k	$400k	$500k	$100k/each
0.5 ME 0.5 SLAC P 0.25 FNAL P	1.0 ME 0.5 SLAC P 0.25 FNAL P 1 M. Des.	1.0 ME 0.5 SLAC P 0.25 CTRLS 1 M. Des.	1.0 ME 0.5 SLAC P 0.25 CTRLS 1 M. Des.	

Changes to 9/2003 Plan

- P0: Existing prototype → RC0
- P1: Inner Mechanism of Mechanical Prototype of LHC Collimator
  - Use UHV components
  - Do NOT use exotic materials (e.g. Be)
  - Measure mechanical performance in air w/ heating/cooling
- P2: UHV Version of P1
  - Measure mechanical perf. in UHV w/ appropriate Heating/cooling

Combine→ RC1

- P3: UHV Version with exact materials for beam tests of wakefields & damage
- ~~P4: DFM version for industry~~ → Drawing package only

Summary of current plan

- FY 2004: Set up lab & Test RC0
- FY 2005: Design, Build, Test RC1
- FY 2006: Design, Build, Non-Beam tests of RC2
- FY 2007: RC2 beam tests & Final drawing package
- FY 2008: Production Support
- FY 2009: Installation & Commissioning support

FY 2004 Goals (1/2)
Set up lab & Test RC0

- Verify the lattice calculations, fault scenarios, and damage estimates that lead to collimator damage
- Specify the mechanical, electric, and vacuum properties of the final collimator
- Hire a devoted mechanical engineer (ME) for the project
- Phase I Material damage tests in FFTB
  - if appropriate and desired by CERN
- Collimator wakefield tests in support of Phase I program as desired by CERN
  - CERN to provide collimator inserts

FY 2004 Goals (2/2)
Set up lab & Test RC0

- Construct an adequate clean room in semi-permanent lab space with
  - HVAC
  - Vacuum system
  - AC Power for
    - 1 kW DC heating
    - 30kW peak heat over a 10 minute period
  - Adequate water cooling for DC and pulsed operation
  - PC/DAQ capability
  - Massive flat support for prototypes
  - Crane access
  - Capacitec measurement system for gap and collimator edge measurements
  - Vacuum diagnostics
  - Temperature diagnostics
  - Hand tools & work bench
- Educate ME by testing the existing NLC prototype "RC0"
  - Transport RC0 to clean room
  - Locate or replace related SLAC built tooling
  - Vacuum test
  - Open and inspect insides
  - Performance tests while open
  - Install (foreseen) new bearing for increased stability
  - Repeat final tests under vacuum

State of Collimator Design (IMHO)

- Beam transport-collimation efficiency-heat load calculations need improvement:
  - a multi-turn simulation aperture that tracks particle loss and energy deposition around the ring needs to be completed
  - The planned graphite collimators survive partially by being rather inefficient, meaning that much of the energy passes downstream to other beam line elements
    - mapping this energy flow has not yet occurred.
- The design parameters for the Phase II collimators have not been specified
  - rather, space has been left for them in the lattice
  - their engineering design will need to be bootstrapped with simulations of their efficiency in absorbing unwanted beam energy for various failure modes

FY 2005 Goals
Design, Build, Test RC1

- **Design, Build, and Test "RC1", a prototype with horizontal jaws, made of non-exotic UHV compatible materials**
  - **Design RC1**
    - Final mechanical specs from 2004 study
    - Assume for now that jaws are 30cm diameter 50cm long cylinders made of a heavy metal (Cu, Fe)
    - Vacuum system appropriate for large collimator
    - Heating elements: Location, Type
    - Cooling channels in cylinders
    - I/O for coolant
    - Monitoring: Thermocouples, Vacuum gauges, Gap Sensors
  - **Build RC1**
    - Interior assembly: Materials, Shop, Assembly
    - Vacuum system: Materials, Shop, Assembly
  - **Test RC1 inner mechanism in air**
  - **Test RC1 under vacuum**
  - **Iterate tests as needed**
- **Hire postdoc to interface with engineer and run tests**
- **Hire designer to help engineer with drawings**
- **Phase I Material damage & Collimator wakefield tests if appropriate and desired**

FY 2006 Goals
Design, Build, Non-Beam tests of RC2

- **Design, Build and Test "RC2", a beam-test capable prototype with exotic materials**
  - **Design RC2**
    - Adapt to exotic materials
      - Cu loaded Carbon, for example, is being considered
    - Control system capability
    - External Mover system
    - Alignment system
    - External BPM system
    - Cooling channels
    - Remote Instrumentation & Control
  - **Build RC2**
    - Parts: BPMs, Movers, Bellows, I&C Hardware
    - Fabrication
    - Assembly
  - **Air test of RC2**
  - **Vacuum Tests of RC2**
  - **Beam tests of RC2**
    - Transport to beam facility
    - Installation
    - Alignment
    - In-situ tests without beam
    - Beam tests
- **Travel for ME, postdoc, physicist**

FY2007-09 Goals

- **2007 Goals : RC2 beam tests & Final drawing package**
  - Finish testing RC2
  - Design and produce complete drawing package for industry-produced collimators
    - As close to RC2 as possible
    - Not thought to need a prototype unless RC2 shows need for substantial design modifications
- **2008 Goals: Production Support**
  - Support the industrial production of the required number (5-10) of collimators, presumably by CERN unless it is decided otherwise at a later date.
- **2009 Goals: Installation & Commissioning support**
  - Participate in installation and commissioning of final collimators

Phase II Collimator Budget Summary

Program Total (k$)	1785	465	588	2838	3310	3310
Item	Salaries	M&S	Shop	Total	Guidance	Full
2004, with overhead, unescalated	163	80	38	281	120	120
2005, with overhead, unescalated	330	96	197	623	300	430
2006, with overhead, unescalated	423	182	326	931	900	870
2007, with overhead, unescalated	423	43	27	493	835	835
2008, with overhead, unescalated	201	11	0	212	740	690
2009, with overhead, unescalated	245	53	0	298	415	365

		FY04	FY05	FY06	FY07	FY08	FY09
Labor count							
Scientist/Engineer	FTE	1.0	1.3	1.5	1.5	0.8	1.0
Post Doc/Student	FTE	0.0	1.0	1.0	1.0	1.0	1.0
Designer/Technician	FTE	0.0	0.5	1.0	1.0	0.0	0.0
TOTAL LABOR	FTE	1.0	2.8	3.5	3.5	1.8	2.0

FY 2004: Set up lab & Test RC0

FY 2005: Design, Build, Test RC1

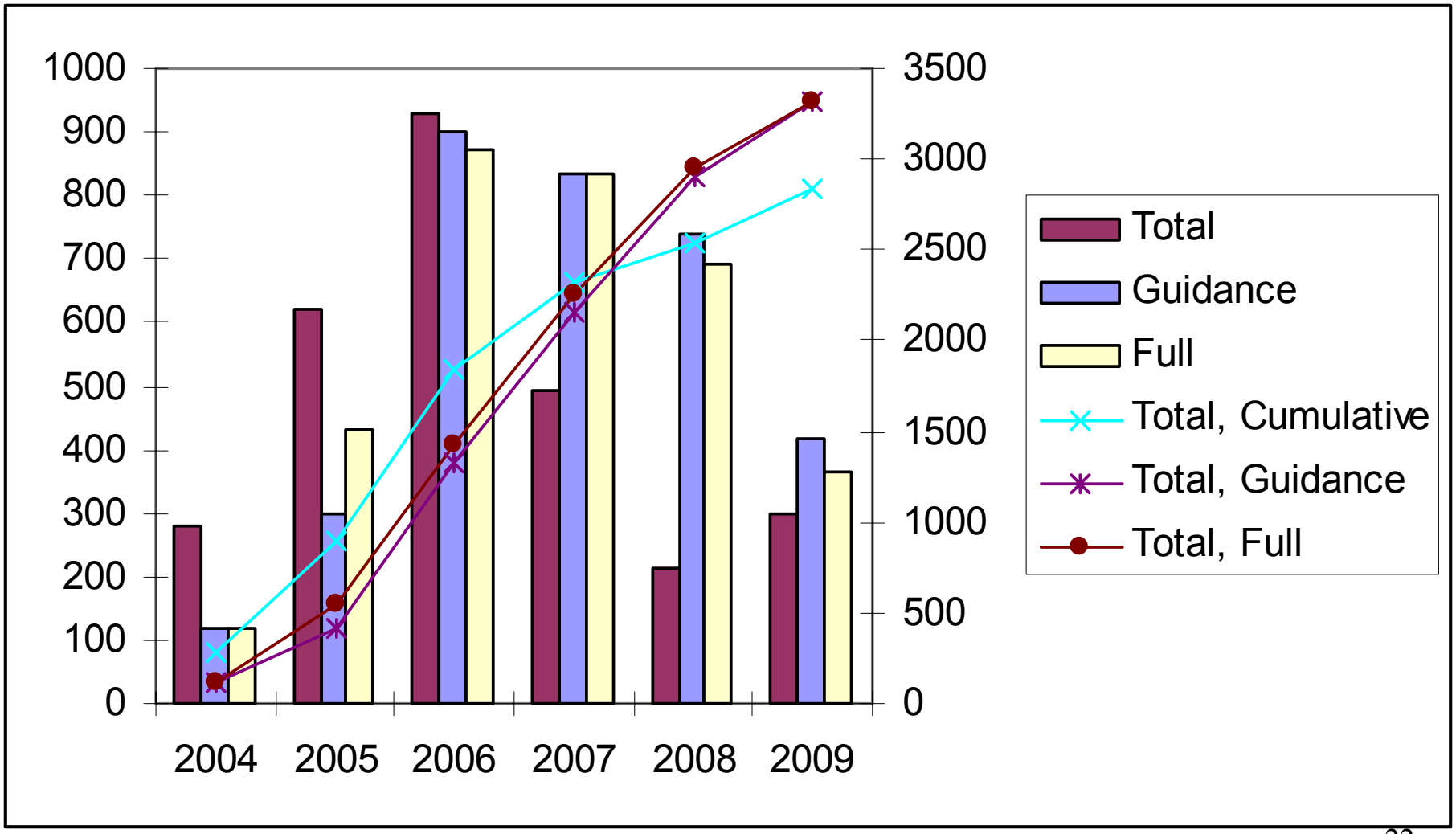
FY 2006: Design, Build, Non-Beam tests of RC2

FY 2007: RC2 beam tests & Final drawing package

FY 2008: Production Support

FY 2009: Installation & Commissioning support

Phase II Collimator Budget Summary



FY 2004: Set up lab & Test RC0

Item	Salaries	M&S	Shop	Total
ME (Full time, 6months)	55			55
Physicist (0.5 FTE)	65			65
Equipped Clean Room		58	5	63
RC0 Tests		7	13	20
Beam Test Support			10	10
Travel		10		10
Contingency				
Total	**120**	**75**	**28**	**223**
With overhead	**163**	**80**	**38**	**281**

FY 2005: Design, Build, Test RC1

Item	Salaries	M&S	Shop	Total
ME (1 FTE)	110			110
Physicist (0.25 FTE)	33			33
Postdoc (1 FTE)	60			60
Mech. Designer (0.5 FTE)	40			40
RC1 Interior				
Parts		50		50
Fabrication (16 man-weeks)			40	40
Assembly (8 man weeks)			20	20
RC1 Vacuum				
Parts		20		20
Fabrication (8 man-weeks)			20	20
Assembly (4 man weeks)			10	10
RC1 Tests & Rebuilds				
Parts		10		10
Fabrication (4 man weeks)			10	10
Assembly (8 man weeks)			20	20
Beam Test Support			25	25
Travel		10		10
Contingency				
Total	**243**	**90**	**145**	**478**
With overhead	**330**	**96**	**197**	**623**

FY 2006: Design, Build, Non-Beam tests of RC2

Item	Salaries	M&S	Shop	Total
ME (1 FTE)	110			110
Physicist (0.25 FTE)	33			33
Postdoc (1 FTE)	60			60
Mech. Designer (1.0 FTE)	80			80
Controls Engineer (0.25FTE)	28			28
RC2 Interior				
Parts		100		100
Fabrication (32 man-weeks)			80	80
Assembly (16 man weeks)			40	40
RC2 Vacuum				
Parts		40		40
Fabrication (16 man-weeks)			40	40
Assembly (8 man weeks)			20	20
RC2 Tests & Rebuilds				
Parts		20		20
Fabrication (8 man weeks)			20	20
Assembly (16 man weeks)			40	40
Travel		10		10
Contingency				
Total	**311**	**170**	**240**	**721**
With overhead	**423**	**182**	**326**	**931**

FY 2007: RC2 beam tests & Final drawing package

Item	Salaries	M&S	Shop	Total
ME (1 FTE)	110			110
Physicist (0.25 FTE)	33			33
Postdoc (1 FTE)	60			60
Mech. Designer (1.0 FTE)	80			80
Controls Engineer (0.25FTE)	28			28
RC2 Beam tests				
Shipping		10		10
Installation, Alignment, Integration			20	20
Beam test travel (1month, 3 people)		20		20
Drawing package for DFM Collimator				
Travel		10		10
Contingency				
Total	**311**	**40**	**20**	**371**
With overhead	**423**	**43**	**27**	**493**

FY 2008: Production Support

Item	Salaries	M&S	Shop	Total
ME (0.50 FTE)	55			55
Physicist (0.25 FTE)	33			33
Postdoc (1 FTE)	60			60
Travel		10		10
Contingency				0
Total	**148**	**10**	**0**	**158**
With overhead	**201**	**11**	**0**	**212**

FY 2009: Installation & Commissioning support

Item	Salaries	M&S	Shop	Total
ME (0.50 FTE)	55			55
Physicist (0.50 FTE)	65			65
Postdoc (1 FTE)	60			60
Beam test Travel (3 people, 2 months)		40		40
Travel		10		10
Contingency				0
Total	**180**	**50**	**0**	**230**
With overhead	**245**	**53**	**0**	**298**